DSIF Uplink Amplitude Instability Measurement

A. Bryan and G. Osborn
DSIF Operations Section

A simple and inexpensive upper bound technique for the measurement of DSIF effective radiated power is described. Test results verify the theoretical model and imply that DSIF uplink stability can satisfy Pioneer F/G attitude control requirements.

I. Introduction

The spin-stabilized *Pioneer F/G* spacecraft will utilize an automatic attitude control system (CONSCAN) based upon RF conical scanning techniques. The uplink RF signal radiated by the DSIF is the reference for the spacecraft attitude control system. The CONSCAN processor cannot distinguish between RF amplitude variations due to spacecraft aiming errors and those due to fluctuations in the DSIF effective radiated power (ERP). This usage of the uplink signal as a beacon required the DSIF to reevaluate its ERP variations. The variations are due to two uncorrelated sources, uplink antenna pointing errors and power variations in the transmitter.

Instability in the transmitter power was monitored with a crystal detector and, with the aid of the frequency translator, the DSIF S-band receiver. The antenna pointing error was evaluated from the ground receiver automatic gain control (AGC) while tracking ALSEP 1, the lunar scientific package. Instability in the uplink due to antenna pointing errors is assumed to be nearly the same as in the downlink signal.

ERP variations detected by the synchronous AGC detector are recorded on digital tape and analyzed off-line. In addition to frequency analysis (i.e., a power spectrum), a chart recorder provides a time domain record for comparison.

II. Validation and Analysis

Software development and validation of the use of the receiver AGC to measure power spectra was done at DSS 71. The spectrum is obtained from the squared magnitude of the discrete Fourier transform in an ensemble averaging mode, wherein many spectra are averaged to reduce the variance of the final estimate. The Fourier transform has a dynamic range of approximately 80 dB, and is adequate for analysis of very small stationary and random signals so long as the thermal noise is not too great.

Figure 1 is the program output for 0.406% rms (0.1 dB peak-to-peak) sinusoidal carrier modulation at 0.08

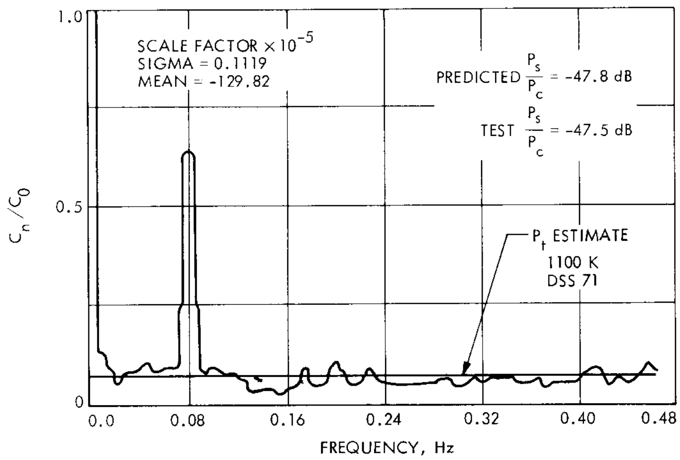

Fig. 1. Fourier transform of 0.1 dB peak-to-peak sine wave modulation at 0.08 Hz

Hz. The signal was generated by modulating the station test transmitter, and was detected from the receiver AGC. To estimate the sideband power P_s, it is noted that the instantaneous power $P(t)$ can be expressed as

$$P(t) = P_c(1 + 2\,m(t))$$

with $< m(t) > = 0$ and $< m^2(t) > \ll 1$. The ratio of sideband to carrier power is just

$$\frac{P_s}{P_c} = < m^2(t) >$$

For the test case, $< m^2(t) > = (4.06 \times 10^{-3})^2 = 1.65 \times 10^{-5}$, or -47.8 dB. To compare this value to the data graphed in Fig. 1, the program output must be interpreted.

The program provides the power density spectrum as a function of frequency (at 0.004 Hz intervals) in the form of the coefficients

$$C_0, C_1, C_2 \cdots C_n$$

C_0 is the carrier term, which is normalized to one. The program returns coefficients representing positive frequencies only, while an equal amount of power is contained in negative frequencies. Each coefficient other than C_0 must therefore be doubled to get the total power.

In order to improve the spectral response, a gaussian time window truncated at the three sigma points was used, but this technique smears the power in the C_0 term. This effect requires the C_0 term to be multiplied by a constant of 2.39[1] or

$$P_c = 2.39\,C_0$$

The gaussian window does not affect the amplitude of a flat spectrum, and has little effect on the power contained in a window spanning many coefficients. The power contained in such a window (with no strong signals near the end points) is then

$$\frac{P_s}{P_c} = \frac{2\sum_{k=i}^{j} C_k}{2.39\,C_0} - \frac{P_t}{P_c} \qquad (1)$$

P_t is the thermal noise power. When Eq. (1) is applied to the test data of the 0.1 dB modulation, the sideband power is -47.5 dB, which compares favorably with the -47.8 dB computed above.

A prediction of thermal noise power with respect to carrier power, considering that the receiver coherent detector enhances carrier power by a factor of two relative to thermal noise, is

$$\frac{P_t}{P_c} = \frac{kT\,\Delta F}{10^{(\mathrm{dBmW}-30)/10}}$$

The signal level in dBmW is obtained from the receiver AGC, k is Boltzmann's constant, T is the system temperature, and ΔF is the bandwidth. Note that the predicted thermal noise level agrees closely with the observed level in Fig. 1.

III. Preliminary Test Results

Using the validated test techniques, preliminary tests of the antenna pointing error were performed at DSS 12. This station tracked ALSEP 1 in both autotrack and APS modes. Figure 2 is a block diagram of the hardware configuration. Results of the APS track are shown in Fig. 3. Note how easily detectable is the 1.6-Hz ALSEP

[1]Determined from the transform of a constant.

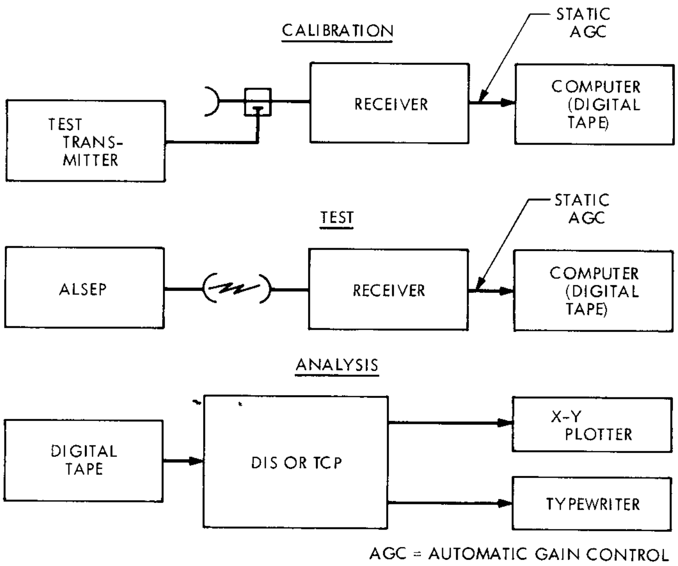

Fig. 2. Station configuration for antenna-pointing error test

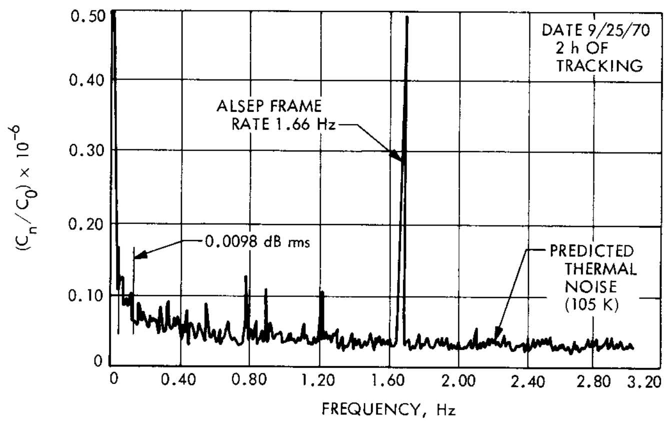

Fig. 3. ALSEP power spectrum (antenna in APS mode)

frame rate as an amplitude modulation. Also clearly evident (at 1.2 Hz) is the effect of the maser amplitude modulation. The thermal noise level is consistent with the predicted thermal noise level. Within the CONSCAN frequency response band, Eq. (1) yields $P_s/P_c = 1.28 \times 10^{-6}$, which is equivalent to 0.0098 dB rms amplitude variation. There is no evidence of a periodic component in this region.

Tests were performed at DSS 11 on the 20-kW transmitter operated at 250 W, 1 kW, and 20 kW. Operation at 250 W was required in order to satisfy an uplink power requirement of the *Pioneer F* and *G* spacecraft during initial maneuvers after launch. Essentially the same technique is used as in the antenna pointing error measurement, as shown in Fig. 4.

Figure 5 shows the results of these three tests. The 20-kW transmitter operating at 250 W revealed the most instability, as expected. Note that the result, 0.0035 dB rms in the CONSCAN frequency band of 0.04 to 0.12 Hz, is strictly an upper bound as the receiver noise is also included in this measurement. To obtain a spectrum of the transmitter amplitude instability without the receiver noise, a crystal detector operating in its linear range was used to detect power variations at 1 and 20 kW.

With the assumption of no correlation between the antenna pointing error and transmitter instability at 250 W, a vector sum result is 0.0135 dB rms. This figure is to be compared to a project suggested value for the DSIF ERP variation of 0.0355 dB rms centered at the maximum response of the CONSCAN attitude control system.

IV. Conclusion

A relatively simple and inexpensive upper bound[2] measurement technique for ERP amplitude variations has been developed and verified. Preliminary tests imply that the DSIF uplink amplitude stability can satisfy *Pioneer F/G* attitude control requirements. The technique will be implemented at all stations supporting *Pioneers F* and *G*, as RF amplitude stability tests will probably be required periodically, as well as following maintenance of subsystems that affect antenna pointing or transmitter stability.

[2]The real part of the cross power spectrum of two receiver outputs would also provide the desired power spectrum, and would reduce the receiver contribution to the measurement.

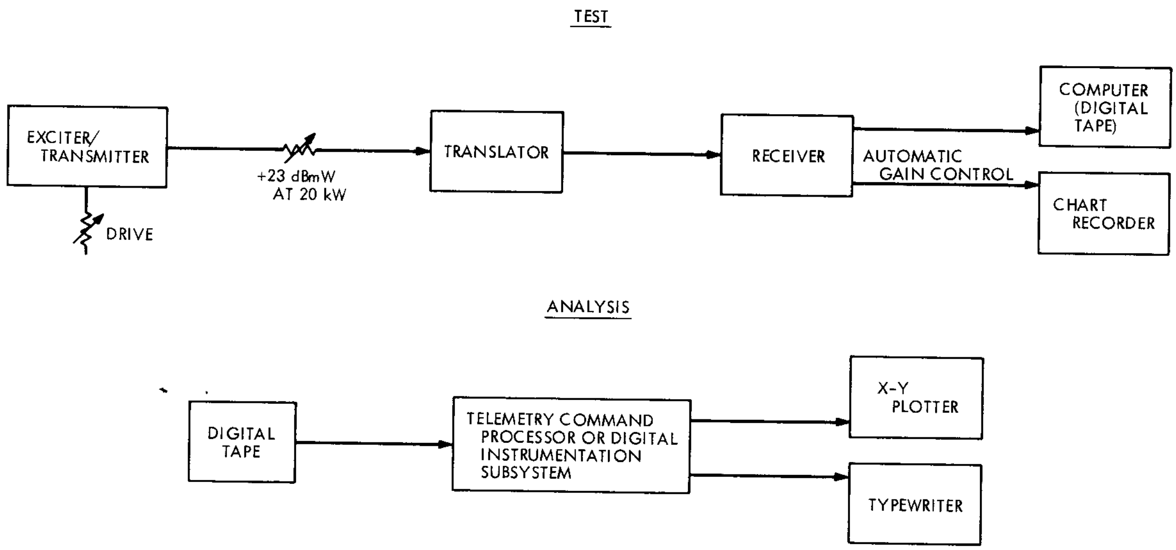

Fig. 4. Transmitter amplitude stability test

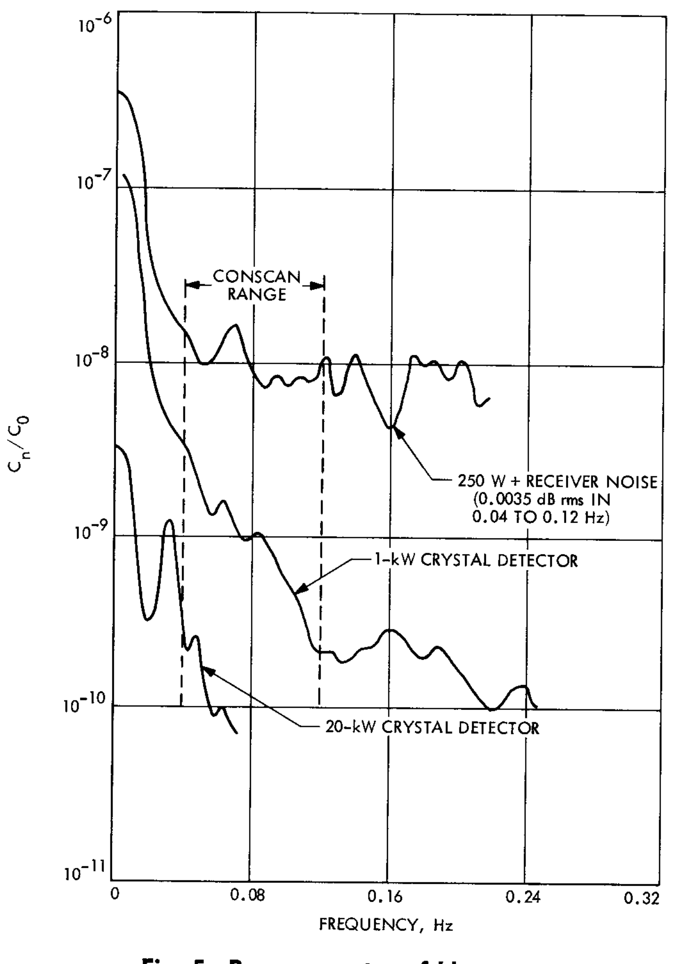

Fig. 5. Power spectra of klystron (antenna moving at sidereal rate)